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Individual variations in eating rate and oral processing behaviours and their association with energy intake and appetite in older adults (≥ 65 years old)

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ABSTRACT

Oral processing behaviours (OPBs) have been repeatedly associated with energy intake and appetite in younger adults; however, in older adults, these associations remain poorly understood. Older adults often experience ageing-related physiological decline, which can affect food oral manipulation and intake. This study investigated individual variations in OPBs and their association with energy intake and appetite in healthy older adults. Eighty-eight participants (44 males, mean age 73.7 SD 5.3 years) attended one visit after an overnight fast. A fixed-portion breakfast was provided and consumed in full, while consumption was video-recorded to quantify OPBs (chews, bites, swallows, chews per bite, bite size, eating rate, meal duration). Self-reported appetite was assessed using visual analogue scales (VAS). Meal energy intake was measured using an *ad libitum* lunch. A weighed food diary was used for the rest of the day to record food and drink intake. Generally, eating rate was negatively correlated with OPBs frequency and duration ($p < 0.001$). OPBs differed between genders and eating rate subgroups. From the postprandial self-reported appetite ratings, in faster compared to slower eaters, "prospective intake" was rated higher, indicating greater perceived appetite. Faster eating rate at the *ad libitum* meal was significantly and independently associated with greater energy intake ($p < 0.001$), when accounting for age, gender, BMI, lunch liking and pre-lunch appetite ratings. This study highlights the link between eating rate and energy intake in older adults and provides insights for future interventions, especially when energy intake needs to be increased in frail older adults.

1. Introduction

Food oral processing behaviours (OPBs), and especially eating rate, are modifiable behaviours that have gained research attention due to their association with energy intake, appetite, and body weight (Andrade et al., 2012; Robinson et al., 2014). In younger adults, food oral manipulation and processing as well as their effect on food and energy intake have been studied extensively. Individuals who consume their food faster consume more energy at that meal (Robinson et al., 2014), which may also affect their post-meal satiety (Goh et al., 2021). Certain elements of eating behaviours have been shown to support increased energy intake through their effects on eating rate. Specifically, adults who take fewer chews before swallowing have shorter oral exposure times per bite, eat at faster rates and consume more energy (Forde et al., 2017). In contrast, more thorough chewing of each bite increases oral exposure time, reduces eating rate, reduces food intake and promotes a stronger satiety response for the same energy consumed (Li et al., 2011; Miquel-Kergoat et al., 2015). Thus, a slower eating rate has been suggested to be beneficial for younger adults (Hawton et al., 2018; Robinson et al., 2014), especially as the prevalence of overweight and obesity is increasing (Sorensen et al., 2022). However, the above

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List of abbreviations used in the manuscript:

BMI	Body Mass Index
CNAQ	Council of Nutrition and Appetite Questionnaire
iAUC	Incremented Area Under the Curve
MNA	Mini Nutritional Assessment
OPB(s)	Oral Processing Behaviour(s)
RISE-Q-15	Reasons Individuals Stop Eating Questionnaire
VAS	Visual Analogue Scales

associations can potentially be a disadvantage for older populations, as their needs and health conditions are different, especially when their appetite is significantly reduced or when they are suffering from undernutrition and related comorbidities.

In older adult populations, oral processing patterns have been studied to a much lesser extent, with most studies focusing on chewing. It is established that ageing involves a decline in oro-sensory and physiological functions and physical abilities, which can lead to problems with chewing and oral manipulation of food (Landi et al., 2013; Mir et al., 2013) and consequently affect the eating process and appetite (Brownie, 2006). Mastication time and time to swallow are longer due to a decrease in the masticatory function (Matsuo & Palmer, 2009), while tooth loss and changes in muscle function can compromise older adults' masticatory efficiency (Fontijn-Tekamp et al., 2000; Miyaura et al., 2000). Older adults require more chewing cycles and a longer chewing duration to reach the swallowing threshold (Mioche, Bourdiol, Monier, et al., 2004; Mishellany-Dutour et al., 2008), which prolongs the oral processing phase and can lead to slower eating rate. Ketel et al. (2019) showed that older individuals require longer consumption times and slower eating rates (g/min) for all liquid, semi-solid and solid foods and more chews per bite for solid foods than younger individuals (Ketel et al., 2019). This could affect the within-meal energy intake and postprandial appetite sensations. Food intake and appetite outcomes in older adults have only been studied in fixed chewing regime studies, however eating rate and other oral processing behaviours have not been explored in these studies. The studies to date have shown that increased chewing during an *ad libitum* meal reduced the eating rate of the meal but did not affect food intake (Zhu & Hollis, 2014), as well as increased feelings of fullness and suppressed hunger for longer (Zhu et al., 2014).

To our knowledge, no studies to date have explored individual variability in OPBs and their association with energy intake and appetite in older adults. At the same time, some of the studies in older adults have only focused on males (Zhu et al., 2014). Ageing affects the two genders differently, with reduced appetite outcomes such as malnutrition being more prevalent in older females (Crichton et al., 2019); thus, studies including both genders are required to provide a full picture of the issue.

The current study investigated individual differences and variability in eating rate and other OPBs and their association with energy intake and satiety in healthy, community-living individuals, aged 65 years old and older. Specifically, the study aimed to (1) describe the range of natural variations in OPBs in a sample of adults 65 years old and older, and explore differences in OPBs between males and females as well as between faster and slower eaters, (2) identify differences in postprandial appetite and satiety between faster and slower eaters, and (3) determine the association between eating rate and energy intake of the *ad libitum* meal.

The above aims led to the following hypotheses:

1. In younger adults, gender has been shown to influence OPBs, with males to have larger average bite sizes (g) and faster eating rates (g/s) compared to females (Ketel et al., 2020). Additionally, in younger adults, OPBs differ between slower and faster eaters, with slower eaters to have more chews per bite and longer oral exposure times (Goh et al., 2021). We hypothesised that in this sample of older adults, the eight measured oral processing behaviours would be significantly different (A) in men and women and (B) in the subgroups of slower and faster eaters. We assumed OPB variability in older adults to be greater than in younger adults, when compared to data observed in the literature, due to the physiological changes that happen with ageing and, as older adults are a diverse group who differ considerably in the biological ageing trajectory (Brownie, 2006; Mioche, Bourdiol, & Peyron, 2004).
2. Several studies have reported that slower eaters experience greater postprandial satiety in younger adults' studies (Li et al., 2011; Miquel-Kergoat et al., 2015). We hypothesised that in older adults, slower eaters would present with greater postprandial satiety than faster eaters.
3. Faster eating rate has been associated with greater energy intake in younger adults' studies (Robinson et al., 2014). We hypothesised that in older adults, similar to younger adults, a faster eating rate would be associated with greater energy intake of the *ad libitum* meal.

2. Methods

2.1. Participants

Healthy male and female participants aged 65 years old or older, living in the wider area of Reading, Berkshire, UK, were recruited using several routes, including University of Reading participant databases, online platforms, poster advertisements and word of mouth. Participants showing interest in the study were contacted for a screening call and, if the eligibility criteria were met, they were booked for the study visit. The exclusion criteria of the study included recent diagnosed dysphagia and/or oral surgery with significant effect on eating or swallowing; existing diagnosis of type 1 or type 2 diabetes; undergoing current treatment for cancer; having no remaining natural teeth; severe loss of appetite and not able to finish a meal; not able to provide informed consent as defined by the T-CogS test (Newkirk et al., 2004) and participants with T-CogS <22 were excluded; having a pacemaker; aversions or allergies/intolerances to any of the two meals provided on the visit day or any food or ingredient included in the meals; not able to feed themselves.

Approximately 120 participants responded to the study call, from which 25 were omitted after the screening call as they did not fulfil the study's inclusion criteria or declined participation due to dislike of the study meals and seven were booked for a visit but did not attend due to unexpected life events. Therefore, a total of 88 participants were recruited.

The study was performed in accordance with the Declaration of Helsinki and was granted ethical approval from the University of Reading Research Ethics Committee (UREC 22/29, 22/10/22). Written, informed consent was obtained from all participants at the beginning of the visit before any data collection commenced.

2.2. Sample size

To define the sample size, power calculations were undertaken through an online power calculator (ClinCalc, 2024) and using a single study group design, continuous primary endpoint, 80% power and alpha <0.05. The calculations were based on previous, published research in young adults (Li et al., 2011), which used food intake as a satiety outcome and assessed the effects of chewing on *ad libitum* energy intake in lean subjects versus subjects with obesity using either 15 or 40 chews per bite. Subjects' energy intake was 11.9% lower after 40 chews than after 15 chews (mean $\pm$ SD: 2614.7 $\pm$ 511.6 kJ compared with 2304.4 $\pm$ 490.4 kJ; p *value* $=$ 0.034). Based on the above calculations, we defined a sample size of 82 people for this study. Participant recruitment was extended to 86 participants to account for 5% dropouts, and the

final number of 88 participants was decided to account for an equal and even number of slower and faster eaters per gender group (44 males and 44 females, with 22 faster and 22 slower eaters per gender group).

2.3. Study design

The study had a cross-sectional design. The eligible participants attended the Hugh Sinclair Unit of Human Nutrition at the University of Reading for 1 study visit, at around 8 a.m. and after a 12-h overnight fast. The total duration of the visit was approximately 5 h. To reduce demand awareness, participants were informed that the aim of the study was to investigate eating styles and were given the following title for the research project: "How much does eating style vary between people?". On the day prior to the visit, participants were asked to restrict their intake of alcohol and caffeine-containing drinks, not have any dental work performed and to restrict any participation in intense physical activity.

2.4. Test meals

At the visit day, participants were provided with two test meals: a fixed-portion breakfast (Test Meal 1) and an *ad libitum* lunch (Test Meal 2), which was provided 3 h after the breakfast meal, following the preload study design (Blundell et al., 2010). 250 mL of water was provided with the meals. Nutritional information and the components of both meals are shown in Table 1.

The fixed-portion breakfast (Test Meal 1) was provided at around 9 am, approximately 1 h after the participant's arrival at the department. Test Meal 1 consisted of a scrambled egg sandwich and was labelled with 100 mg of ^{13}C-octanoic acid (CK Isotopes Ltd., Leicestershire, UK) for measurement of gastric emptying (Ghoos et al., 1993). This meal was selected as it is very similar to the standard meal described in the gastric emptying method's protocol by Ghoos et al. (1993). The octanoic acid did not affect the taste or the physical characteristics of the meal and the overall breakfast liking was more than 50%, as rated using post-meal visual analogue scales (VAS) ratings (Mean 62.6, SD 20). Results from the gastric emptying measurements are not presented in this paper. Participants were asked to consume Test Meal 1 in full (as a means of standardising appetite before the *ad libitum* intake later in the day) at their natural pace and a 15-min timeframe was allowed for consumption. All participants complied with the instructions.

Three hours after Test Meal 1, Test Meal 2 (*ad libitum* lunch) was provided. This *ad libitum* lunch consisted of a pasta dish, which is a commonly used for *ad libitum* meals in appetite studies. The provision of the *ad libitum* meal took place using the multiple bowls method, which has been used previously (Hobden et al., 2017), aiming to avoid presenting participants with a "set portion of food" (Ello-Martin et al., 2005), which may be overwhelming, especially for an older adults' population. A portion of 255 g of the meal was served warm in a medium-sized bowl. After around 5 min, or when the participant had consumed 60–70% of the bowl, another fresh, identical bowl of food was served to replace the previous one, to prevent visual feedback of food consumed and any tendency to finish the provided portion. This process continued with fresh, identical bowls being served every 5 min or whenever 60–70% of the previous bowl was consumed. Participants were instructed to eat until they feel comfortably full and indicate when they had finished their meal. The average number of bowls used for each participant was three. All bowls were weighed before being provided to the participants and after being taken away from them and the total amount of food (g) and energy (kcal) consumed were calculated.

2.5. Data collection and analysis

Fig. 1 shows a timeline of the study visit, including only the assessments whose results are presented in this paper.

2.5.1. Body composition and other data collection

Body composition data including weight, height, lean body mass and body fat mass (kg and %) were collected on arrival using bioimpedance scales (Tanita; BC–418 MA; Tokyo, Japan) while participants were in a fasted state.

The following measurements were collected but not reported in the results of the current paper: Unstimulated and stimulated saliva for assessing salivary flow rates and salivary α-amylase activity; chewing efficiency using a 2-colour chewing gum test; bolus saliva uptake; postprandial repeated blood samples for reporting glucose and insulin responses; and repeated postprandial breath samples for assessing gastric emptying. The details of all the methods can be found on the clinical trials registration website (ClinicalTrials.gov; Project ID: NCT05671003).

2.5.2. Oral processing behaviours (OPBs)

Participants' OPBs were video recorded during Test Meal 1 for post-hoc behavioural coding using a technique previously described elsewhere (Forde et al., 2013). Briefly, participants were seated at a quiet booth and a laptop fitted with a webcam was placed approximately 30 cm away. Participants were instructed to consume the breakfast meal (scrambled egg sandwich) using their hands. Participants had access to 250 mL of water during the session; however, they were advised to consume water either before starting or after finishing the meal to avoid confusion of eating and drinking motions while coding. During the meal, the researcher was in the same room to observe the procedure, but out of sight of the participants to avoid influencing their eating behaviour. Participants were not able to see themselves on the camera; however, they were informed prior to the session that they would be video recorded whilst eating and they had provided their written consent.

Table 1
Test Meal 1 (fixed-portion breakfast) and Test Meal 2 (*ad libitum* lunch, calculated per 255g bowl serving) composition and nutritional value of components.

	Test Meal 1: Breakfast (per 115.7g portion)				Test Meal 2: Lunch (per 255g serving bowl)			
	Egg (50g)	**Butter (8g)**	**White bread (2 slices, 57.7 g)**	**Total (115.7 g)**	**Pasta (cooked, 179 g)**	**Tomato and basil sauce (71 g)**	**Grated parmesan cheese (5 g)**	**Total (255g)**
Energy (kcal)	68.5	56.5	140	265	316	71	26.5	413.5
(kJ)	286.6	236.3	585.7	1108.7	1322.1	297.0	110.8	1730.0
Fat (g)	5	6.2	1.2	12.4	1.1	4.3	1.9	7.3
of which saturates (g)	1.6	2.8	0.2	4.6	0.3	0.3	1.3	1.9
Carbohydrates (g)	0.2	0.05	26.2	26.45	63.9	5.7	0.2	69.8
of which sugars (g)	0.2	0.05	1.6	1.85	2	3.9	0	5.9
Protein (g)	5.5	0.04	5.2	10.74	10.4	1.6	2.1	14.1
Fibre (g)	0	0	1.2	1.2	3.9	1.3	0	5.2
Salt (g)	0.01	0.07	0.6	0.68	0.1	1.0	0.1	1.2

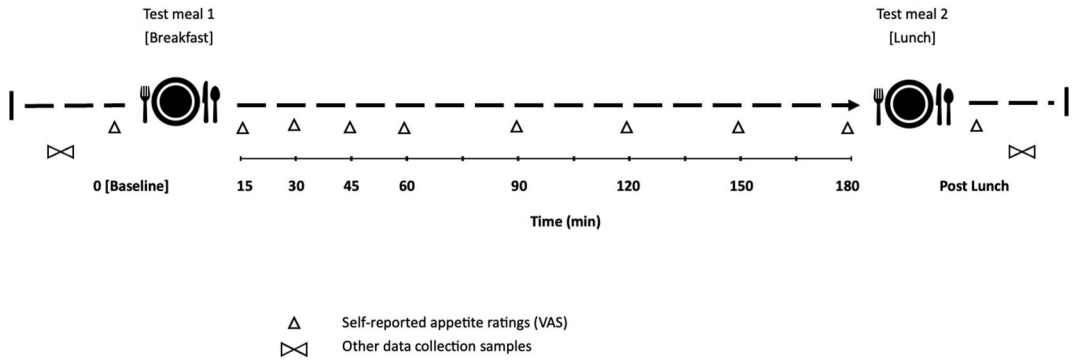

Fig. 1. Schematic representation of the visit day's timeline and methodologies. VAS: visual analogue scales. The "Other data collection samples" included anthropometric measures, the Council of Nutrition and Appetite Questionnaire (CNAQ), the Mini Nutritional Assessment (MNA), the Reasons Individuals Stop Eating short questionnaire (RISE-Q-15), a self-reporting tooth counting questionnaire and a general information questionnaire.

A behavioural annotation software (ELAN 4.9.1, Max Plank Institute for Psycholinguistics, The Language Archive, Nijmegen, the Netherlands) was used to code each video recording of the breakfast sessions for OPBs (Fogel et al., 2017). Frequencies of the three key events (bites, chews and swallows) were coded using a pre-defined coding scheme developed previously (Forde et al., 2013). Total oral exposure time (min) was also simultaneously coded. Total oral exposure time was defined as the time the food spent in the mouth. Total meal duration time (min) was calculated as the sum of total oral exposure time and the time spent with no food in the mouth (inter-bite interval in minutes). Further OPBs were calculated in combination with the weight of the food consumed at breakfast (117 g). Specifically, the eating rate (g/min) was calculated by dividing the food consumed (117 g) by the oral exposure time (min). The average bite size (g/bite) and number of chews taken per bite (chews/bite) were also calculated. All behavioural coding was completed by a trained researcher (DZ). Validation coding was conducted by a second, trained researcher (MC) for a minimum of 10% of the total coded videos and had to show at least 80% agreement between coders for the data to be accepted for analysis.

For Test Meal 2 (*ad libitum* lunch), the total duration of the meal (min) was defined as the time from when the first bowl was provided until the participant indicated having finished the meal and the last bowl was taken away. The eating rate of Test Meal 2 was calculated by dividing the total food (g) consumed via the total duration of the meal (min). This is a method that has been used previously (Andrade et al., 2012). Test Meal 2 consumption time was not recorded for 12 participants due to inability to retrieve the eating time for the *ad libitum* meal; hence, eating rate at Test Meal 2 and analyses including this variable were included for 76 participants.

2.5.3. Appetite ratings

To assess self-reported hunger, satiety, fullness, prospective food intake and desire to eat, visual analogue scales (VAS) were used, which were 100 mm in length and anchored with positive and negative ends (e.g., "How hungry do you feel right now?" 0-not at all, 100-extremely) (Flint et al., 2000). Alongside the hunger and satiety ratings, "Mood Ratings" were also included as distractor ratings and were specifically assessing how 'happy', 'calm and 'energetic' the participants felt (e.g., How happy do you feel right now? 0-not at all, 100-extremely). Participants were asked to complete these ratings before Test Meal 1 and then for the 3 h postprandially at the following timepoints (min): 15, 30, 45, 60, 90, 120, 150, 180. Participants also completed ratings at a final "post-lunch" timepoint immediately after Test Meal 2 consumption. Furthermore, at the 15-min rating and at the "post lunch" rating, four more ratings were collected on the liking of the 'taste', 'smell', 'appearance' and 'overall liking' of the meal (e.g., "How much did you like the taste of the meal?" 0-not at all, 100-extremely). All VAS data were collected and managed using REDCap electronic data capture tools hosted at the University of Reading (Harris et al., 2009, 2019) and participants were provided with a study tablet to complete them at each timepoint.

2.5.4. Questionnaires

Questionnaire data were collected and managed using REDCap electronic data capture tools hosted at the University of Reading (Harris et al., 2009, 2019). Questionnaire data reported in this paper included data from a generic health and lifestyle questionnaire, the Council of Nutrition Appetite Questionnaire (CNAQ) (Hanisah et al., 2012), the MNA® (Mini Nutritional Assessment) (Kaiser et al., 2009) and a self-reported tooth counting questionnaire, which included information on denture wearing and overall oral condition (Allen et al., 2005).

Furthermore, the RISE-Q-15 questionnaire was used, which is a shortened version of the RISE-Q (Reasons Individuals Stop Eating Questionnaire) (Chawner et al., 2022) and assesses individual differences in their trait experiences of satiation. RISE-Q-15 measures five satiation processes involved in meal termination at a typical dinner meal at home: Decreased Food Appeal (stopping as a result of hedonic decline), Physical Satisfaction (stopping due to physiological feelings of fullness), Planned Amount (stopping after having consumed a pre-planned amount of food), Self-Consciousness (stopping as a result of social influences and negative feelings about the amount eaten), and Decreased Priority of Eating (stopping as a result of decline in motivation or interest in eating). Participants responded to each item using a seven-point frequency scale ranging from "never" (1) to "always" (7). The score of each scale is calculated as the mean of the individual items comprising each of the five respective scales (Cunningham et al., 2021). Cronbach's alpha for each of the five RISE-Q factors indicated acceptable to high levels of internal consistency in previous research (Chawner et al., 2022). In this study, Cronbach's alpha showed acceptable levels for "Decreased food appeal (Cronbach's $\alpha = 0.734$), Physical Satisfaction (Cronbach's $\alpha = 0.755$) and Planned Amount (Cronbach's $\alpha = 0.743$) and poor levels for Self-Consciousness (Cronbach's $\alpha = 0.573$) and Decreased Priority of Eating (Cronbach's $\alpha = 0.599$).

Further questionnaire data were collected, the outcomes of which are not reported in this paper: the Xerostomia assessment questionnaire (Thomson et al., 1999) and the mouth behaviour questionnaire (Jeltema et al., 2015).

All questionnaires were completed during the 3 h between breakfast and lunch, apart from the ones that could possibly affect appetite, which were completed either before breakfast (CNAQ, mouth behaviour) or after lunch (RISE-Q-15).

2.5.5. Dietary intake for the rest of the day

Food intake for the rest of the day in a free-living environment was recorded using a weighed food diary completed by the participant on paper. This method has been used previously in studies assessing

appetite (Dericioglu et al., 2023). Participants were provided with instructions on how to complete the food diary and with kitchen scales (if not owned). After completion, food diaries (and scales) were returned to the researchers and data were analysed using the Nutritics® dietary assessment software (Nutritics, 2019) to calculate total energy intake for the rest of the day.

2.6. Statistical analysis

The study's aim and hypotheses were specified prior to data collection. All variables were tested for normality visually and statistically using the quantile-quantile plot (normal Q-Q plot) and histogram prior to any statistical comparison. All variables were assessed for outliers using Tukey's method and each analysis was conducted twice, both with and without outliers. All results are presented including outliers (where identified), as the presence of outliers did not change the significance of the results (as defined using $p < 0.05$) in any of the parameters presented. Descriptive data are presented as mean and standard deviation (SD), unless otherwise stated.

A binominal eating rate variable was created for the purposes of comparing faster and slower eater's general characteristics and their self-reported appetite ratings. To create this variable, while avoiding the eating rate gender bias (as males were significantly faster eaters than females), a median split of the continuous variable of eating rate (g/min) from Test Meal 1 (fixed-portion breakfast) was firstly used within males and within females separately and the faster and slower eaters of each gender were then collated together to create the binominal eating rate variable. Using the median split to create the eating rate binominal variable has been previously used in younger adults' studies (Goh et al., 2021).

The first aim was to describe the range of natural variations in OPBs in older adults and the differences between (A) males and females and (B) slower and faster eaters. Independent samples t-tests were used to assess the significance of observed differences between the (A) and the (B) groups for continuous variables (age, weight, % fat mass, % lean body mass, BMI, oral processing characteristics, number of natural teeth, RISE-Q-15, overall liking of the meals) and the Chi-square test of independence and Pearson's Phi coefficient to assess the significance of associations for categorical variables (CNAQ, MNA, presence of partial dentures). These results were analysed using descriptive statistics and presented as mean and standard deviation. Effect sizes were explored and expressed using Cohen's d for all continuous variables (with 0.2 to indicate small effect size, 0.5 medium effect size and 0.8 large effect size) and Cramer's V for all categorical variables (with a range from 0 to 1 and higher values to indicate a stronger correlation between the two variables).

Correlation analysis (Pearson's r) was conducted to test associations between the eight oral processing characteristics studied (bites, chews, swallows, eating rate, chews per bite, bite size, oral exposure time and total meal duration). To protect the family-wise error rate (Type 1 Error) in the total 28 pairwise correlations explored, the level of significance was adjusted using Bonferroni Correction.

The second aim was to identify differences in self-reported postprandial appetite and satiety between faster and slower eaters. To achieve this, analysis of covariance (ANCOVA) was used for each postprandial appetite VAS parameter (hunger, desire to eat, prospective intake, fullness, satiety) with their baseline VAS ratings used as a covariate to examine differences in all self-reported appetite ratings for the 3 h postprandially. Additionally, a combined VAS parameter was created ("overall appetite") by using the average of the following parameters: hunger, desire to eat, prospective intake, reversed fullness (100-fullness) and reversed satiety (100-satiety). The analysis of covariance explored a two-way interaction for each VAS parameter over time (time*VAS) and a three-way interaction when the eating rate group factor was added (time*VAS*eating rate group). The incremental area under the curve (iAUC) for each appetite parameter was calculated using the trapezoidal rule (Blundell et al., 2010) in order for appetite to be included as a single variable in the multivariable model mentioned below.

The third aim of this study was to determine the association between eating rate and energy intake of the *ad libitum* meal. Multiple regression analysis was used to test the relationship between eating rate of the *ad libitum* meal (independent variable) and energy intake of the *ad libitum* meal (dependent variable), controlling for other individual characteristics (covariates), which included gender, BMI, age, Test Meal 2 overall liking rating and pre-Test Meal 2 overall appetite rating (iAUC). Results are presented using standardized (β) and unstandardized (b) regression coefficients, bootstrapped 95% confidence intervals (95% CI) and p values.

Correlation analysis (Pearson's r) was conducted to test the association between eating rate at the fixed-portion breakfast (Test Meal 1) and eating rate at the *ad libitum* lunch (Test Meal 2). Intra-class correlation coefficient (ICC) with 95% confidence interval (CI) was used to examine the consistency of eating rate within individuals across the two test meals (breakfast and lunch).

All statistical analyses were conducted in SPPS Version 27.0, IBM Corp., 2020. Armonk, NY (IBM, 2020) and p value < 0.05 was considered statistically significant (unless otherwise stated).

3. Results

3.1. OPBs' variability within older adults and comparisons by gender and eating rate group (Hypothesis 1)

Eighty-eight participants were analysed, 96.5% of white ethnicity and 90% in the normal (18.5–24.9) or overweight (25–29.9) BMI category. Participant characteristics are presented in Table 2. Variability is shown as Standard Deviation (SD) in all OPBs. Additionally, comparisons by gender and eating rate are presented. Males ($N = 44$) and females ($N = 44$) showed statistically significant differences with medium to large effect sizes in several OPBs, with females consuming the meal with more bites and swallows, a smaller bite size, a slower eating rate and a longer duration of the Test Meal 1 than males, but no significant differences in chews and chews per bite. Females had lower body weight, BMI and percentage of lean body mass, higher percentage of fat mass and rated higher the "Decreased food appeal" question from RISE-Q-15 than males. Males and females did not differ in their overall liking ratings of the test meals (Table 2).

Slower eaters ($N = 44$) when compared with faster eaters ($N = 44$) consumed Test Meal 1 with more bites, chews and swallows, a smaller bite size and more chews per bite, a slower eating rate and a longer duration of the meal (Table 2). All showed large effect sizes. Additionally, the slower eaters' group was significantly older than the faster eaters' groups and scored significantly higher in the "need for frequent appetite reassessment" as identified by the CNAQ. Lastly, faster eaters rated higher the overall liking VAS of both test meals (Table 2).

The mean *ad libitum* energy intake was 575 (SD 239) kcal and males' energy intake (Mean 640 SD 264) was greater than females (Mean 509 SD 193), $p = 0.009$ (results not shown). The ICC between the eating rate at breakfast and eating rate at lunch was $r = 0.313$, $p = 0.006$ (results not shown).

Table 3 shows the correlations between eating rate at Test Meal 1 and the other OPBs. All the OPBs were linearly correlated with eating rate, while significant correlations were found in between most of the oral processing behaviors, after adjusting the statistical significance using Bonferroni Correction. Eating rate was positively associated with bite size and negatively associated with total oral exposure time, total meal duration, chews per bite and total number of bites, chews and swallows (Table 3).

Table 2
Participant characteristics for all sample (N = 88), males (N = 44), females (N = 44), slower eaters (N = 44) and faster eaters (N = 44).

Participant characteristics	All, N = 88	Males, N = 44	Females, N = 44	Significance of gender (p value)	Effect size of gender	Faster eaters, N = 44 (Males N = 22, Females N = 22)	Slower eaters, N = 44 (Males N = 22, Females N = 22)	Significance of eating rate group (p value)	Effect size of eating rate group
Age, years	73.7 (5.3)	74.3 (6.0)	73.1 (4.5)	0.289	0.228	72.3 (0.7)	75.1 (0.8)	0.012	−0.550
Body weight, kg	73.6 (15.1)	83.9 (12.8)	63.2 (8.9)	<0.001	1.872	73.6 (14.5)	73.5 (15.8)	0.991	0.002
Body fat mass, %	29.9 (6.9)	26.1 (5.1)	33.7 (6.5)	<0.001	−1.285	29.8 (6.3)	30.0 (7.6)	0.893	−0.029
Lean body mass, %	70.0 (6.9)	73.8 (5.1)	66.2 (6.5)	<0.001	3.334	70.1 (6.3)	69.9 (7.6)	0.885	0.026
BMI, kg/m^2	25.3 (3.4)	26.6 (3.2)	24.0 (3.1)	<0.001	0.812	25.3 (3.3)	25.3 (3.5)	0.978	−0.006
Oral processing characteristics (Test meal 1)									
Bites, n	13.4 (3.1)	12.6 (2.8)	14.3 (3.2)	0.014	−0.535	12.2 (2.2)	14.6 (3.5)	<0.001	−0.819
Chews, n	427.6 (140.1)	399.0 (137.6)	456.3 (138.3)	0.055	−0.415	336.3 (84.9)	518.9 (124.4)	<0.001	−1.714
Swallows, n	18.3 (5.7)	16.7 (4.3)	19.9 (6.5)	0.008	−0.578	15.5 (4.0)	21.2 (5.7)	<0.001	−1.139
Eating rate, g/min	23.1 (7.9)	26.2 (9.0)	19.9 (5.1)	<0.001	0.855	28.2 (8.0)	18.0 (3.3)	<0.001	1.664
Bite size, g/bite	9.3 (1.8)	10.0 (1.9)	8.6 (1.5)	<0.001	0.772	9.9 (1.7)	8.6 (1.7)	<0.001	0.759
Chews per bite, n	33.7 (12.0)	33.6 (11.5)	33.9 (12.6)	0.919	−0.022	28.7 (8.2)	38.8 (13.1)	<0.001	−0.924
Total duration of meal, min	6.1 (1.8)	5.4 (1.6)	6.7 (1.6)	<0.001	−0.796	4.8 (0.9)	7.4 (1.5)	<0.001	−2.007
Number of natural teeth, n	24.5 (4.8)	24 (5.1)	25.1 (4.4)	0.253	−0.245	24.6 (5.1)	24.5 (4.5)	0.895	0.028
Presence of partial dentures				0.401	0.091			0.780	0.030
Yes, n (%)	15 (17)	9 (20.5)	6 (13.6)			7 (15.9)	8 (18.2)		
No, n (%)	73 (83)	35 (79.5)	38 (86.4)			37 (84.1)	36 (81.8)		
Malnutrition Status (MNA)				0.08	0.188			0.562	0.063
Malnourished	0	0	0			0	0		
At risk of malnutrition, n (%)	3 (3.4)	0	3 (6.8)			2 (4.5)	1 (2.3)		
No risk of malnutrition, n (%)	85 (96.6)	44 (100)	41 (93.2)			42 (95.5)	43 (97.7)		
General appetite (CNAQ)				0.507	0.072			0.015	0.286
At risk for anorexia	0	0	0			0	0		
Need frequent appetite reassessment, n (%)	10 (11.4)	6 (13.6)	4 (9.1)			1 (2.3)	9 (20.5)		
Not at appetite loss risk, n (%)	78 (88.6)	38 (86.4)	40 (90.9)			43 (97.7)	35 (79.5)		
[a]**Reasons to stop eating (RISE-Q-15)**									
Decreased food appeal, n (%)	1.1 (0.8)	0.8 (0.8)	1.3 (0.8)	0.020	−0.507	1.0 (0.8)	1.1 (0.9)	0.340	−0.623
Physical Satisfaction, n (%)	4.1 (1.0)	3.9 (1.0)	4.3 (0.9)	0.099	−0.355	4.0 (1.0)	4.2 (0.9)	0.311	−0.636
Planned amount, n (%)	7.0 (1.2)	6.8 (1.6)	7.2 (0.7)	0.083	−0.374	6.9 (1.4)	7.1 (1.0)	0.333	−0.626
Self-Consciousness, n (%)	4.2 (2.7)	4.4 (2.7)	4.1 (2.8)	0.644	0.099	4.3 (2.6)	4.1 (2.8)	0.700	−0.336
Decreased priority of eating, n (%)	2.6 (2.4)	2.4 (2.5)	2.7 (2.2)	0.461	−0.158	2.5 (2.5)	2.6 (2.3)	0.897	−0.446
Overall liking ratings of study meals (VAS)									
Fixed portion breakfast liking (Test Meal 1), mm	62.6 (20.1)	64.4 (17.7)	60.9 (22.4)	0.422	0.172	67.4 (18.3)	57.9 (20.9)	0.026	0.483
[b]*Ad libitum* lunch liking (Test Meal 2), mm	73.3 (19.0)	71.6 (19.3)	74.9 (18.7)	0.419	−0.173	79.1 (14.8)	67.9 (21.2)	0.006	0.651

Values are presented as Mean (SD); Independent samples T-test; p value < 0.05 is considered statistically significant. MNA = Mini Nutritional Assessment; CNAQ= Council of Nutrition and Appetite Questionnaire; VAS= Visual Analogue Scales; Effect size is expressed as Cohen's d for continuous variables (age, body weight, body fat mass, body lean mass, all oral processing characteristics, number of natural teeth, all Reasons to Stop Eating categories, overall liking ratings of study meals) and Cramer's V for categorical variables (Malnutrition status, Presence of dentures, General appetite).

[a] Reasons to stop eating (RISE-Q-15) expressed as n (%) when the response was either often, frequently or always.

[b] Faster and slower eaters for the *ad libitum* lunch liking are defined from the eating rate of the *ad libitum* lunch, N = 76 (faster eaters N = 38, slower eaters N = 38).

Table 3
Correlations between eating rate and oral processing behaviors during the fixed portion breakfast meal (Test Meal 1).

	Oral exposure time	Bites	Chews	Swallows	Total meal duration	Bite size	Chews per bite
Eating Rate	−0.904***	−0.419***	−0.815***	−0.524***	−0.864***	0.456***	−0.572***
Oral exposure time		0.411***	0.896***	0.583***	0.957***	−0.408***	0.649***
Bites			0.332	0.585***	0.416***	−0.894***	−0.230
Chews				0.461***	0.857***	−0.301	0.821***
Swallows					0.588***	−0.608***	0.075
Total meal duration						−0.395***	0.613***
Bite size							0.272

***$p < 0.0018$; $p < 0.0018$ is considered statistically significant after adjustment for Bonferroni Correction. Values expressed as Pearson's r.

3.2. Eating rate and post-prandial appetite ratings (Hypothesis 2)

There was a significant interaction between appetite and time in all appetite parameters ($p < 0.05$), as shown in Fig. 2(a–f). A significant interaction between time, appetite and eating rate was also found for the "Prospective Intake" parameter (Fig. 2b). Faster eaters rated this parameter higher (mean difference = 6.51, SD = 3.20), showing greater self-reported prospective intake than slower eaters over the 3 h post-prandially. No significant interaction was found between time, appetite and eating rate groups in any of the other appetite parameters ($p > 0.05$). The iAUC for all self-reported appetite ratings did not show significant differences between faster and slower eaters (Supplementary

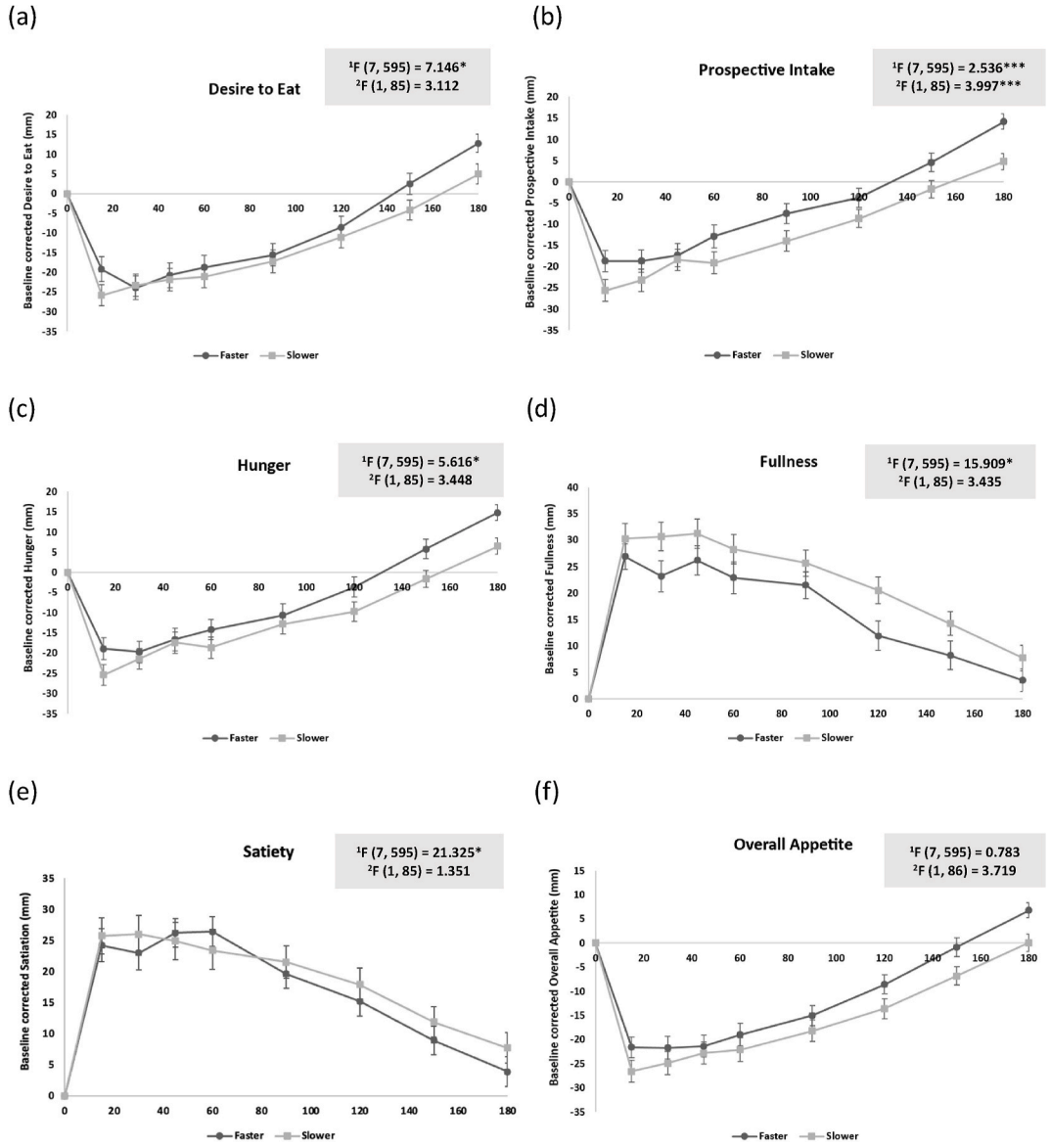

Fig. 2. (a–f): Appetite change ratings (a) Desire to eat; (b) Prospective intake; (c) Hunger; (d) Fullness; (e) Satiety; (f) Overall appetite rating; between faster (N = 44) and slower eaters (N = 44) from baseline (0) to 180min, corrected for baseline rating. Timepoint values are presented as means; Error bars are presented as Standard errors; ^{1}F: F value for time*VAS ratings interactions; ^{2}F: value for time*VAS rating*eating rate interaction; *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; $p < 0.05$ is considered statistically significant.

Table 1).

3.3. Test meal 2: energy intake at the ad libitum meal and association of meal's eating rate with energy intake (Hypothesis 3)

In multiple regression analysis, the eating rate of Test Meal 2 was significantly associated with energy intake at the end of the meal when covariates gender, BMI, age, Test Meal 2 overall liking and pre-Test Meal 2 self-reported appetite (overall VAS score) were included (Table 4).

No significant association was found between the eating rate of Test Meal 2 and the energy intake for the rest of the day, as reported from the food diaries ($r = -0.072$, $p = 0.537$).

4. Discussion

This study aimed to explore individual variability in eating rate and OPBs and associations of eating rate with appetite and energy intake in healthy, community-living individuals aged ≥65 years old. Following the study hypotheses, it was demonstrated that OPBs differed between gender and eating rate subgroups. OPBs were significantly correlated with eating rate and each other (Hypothesis 1). Those defined as faster eaters at Test Meal 1 rated higher the self-reported "Prospective Intake" across the 3 h postprandially, but no further differences were found between faster and slower eaters in any of the other appetite ratings (Hypothesis 2). Eating rate was significantly associated with food and energy intake of the *ad libitum* meal when factors age, gender, pre-meal appetite and meal liking were controlled for as covariates (Hypothesis 3).

In agreement with Hypothesis 3, we showed that faster eating rate was associated with greater energy intake in older adults. This aligns with previous findings in younger adults (Robinson et al., 2014). Several mechanisms have been suggested to explain this association, including the effect of food oral processing on satiety hormones, sensory exposure and palatability. Specifically, eating rate and chewing frequency can influence satiety hormones (Karl et al., 2013). Increased chewing has been linked to higher postprandial levels of insulin, glucose, CCK and GIP and consequently enhanced satiety (Zhu et al., 2013). However, these associations have been equivocal (Cassady et al., 2009). Slower eating rate has been associated with longer sensory exposure per unit of food (Forde et al., 2013), which has been independently linked to lower energy intake (Bolhuis et al., 2014; Bolhuis et al., 2011). The increased chewing and longer oro-sensory exposure that are associated with slower eating rates may also be linked with decreased meal palatability. Meal palatability naturally decreases with repeated consumption, such that the hedonic valence of an initially liked stimulus will decrease through a process of sensory-specific satiety (Havermans et al., 2009). While these mechanisms have been primarily explored in younger adults, they may also apply to the healthy, community-living older adults that were the focus of this study.

Hypothesis 2 proposed that slower eaters would experience greater postprandial satiety than faster eaters. This was confirmed only through the "Prospective intake" ratings, where faster eaters rated their prospective intake higher than slower eaters over the 3 h postprandially. No other appetite ratings differed between faster and slower eaters. The iAUC did not differ by eating rate for any of the appetite parameters. A meta-analysis of studies in younger adults reported no difference in hunger at 180 min post-meal between faster and slower eaters (Robinson et al., 2014). In older adults, appetite has been measured in studies that manipulated the chewing regimes, but their results are inconsistent. Zhu and Hollis (2014) found no effect on self-reported appetite ratings, while Zhu et al. (2014) reported lower hunger and desire to eat with increased chewing. These results should be interpreted cautiously, as altering eating rate by using external manipulations, such as verbal instructions to amend habitual chews may disrupt the normal eating experience (Forde et al., 2013; Ioakimidis et al., 2011). Lastly, appetite dysregulation, which is prevalent among older individuals, has previously been linked to decreased food intake. Indeed, the central feeding system undergoes significant changes during the ageing process, which may affect the appetite and the feeding process (Landi et al., 2013). In our study, this was supported through the CNAQ results, which showed that slower eaters were significantly more in need of "frequent appetite reassessment" (Table 2).

Hypothesis 1 explored OPBs and showed differences between males and females, as well as between faster and slower eaters. Females consumed the Test Meal 1 with more bites and swallows, smaller bite sizes, slower eating rates and longer meal durations. Similar gender influences on OPBs have been observed in younger adults (Ketel et al., 2019; Park & Shin, 2015). Gender differences in oral physiology and anatomy could influence OPBs (Palinkas et al., 2010; Percival et al., 1994) and persist into older age (Crow & Ship, 1996; Percival et al., 1994). Females rated "decreased food appeal" (at RISE-Q-15) as a more prominent reason to terminate a meal. Since females were slower eaters than males, the longer meal duration and longer oro-sensory exposure they experienced may lead to greater hedonic decline and meal termination (Smeets & Westerterp-Plantenga, 2006). However, in this study, both genders rated meal liking similarly after both Test Meal 1 and Test Meal 2 consumption.

In our study, faster eating rate was significantly correlated with fewer bites, chews, chews per bite and swallows, shorter total oral exposure time, meal duration and with a larger average bite size. These associations are consistent with findings in children's and younger adults (Fogel et al., 2017; Forde et al., 2013). Hypothesis 1 also suggested that older adults would demonstrate greater variability in OPBs than younger adults. As different food items have been used in different studies, we aimed to compare our results to results from similar food items in the literature. Thus, the scrambled egg sandwich (from our Test Meal 1) was compared with a "soft sandwich" option used in the younger adults' study of Forde et al. (2017), while the pasta dish (from our Test Meal 2) was compared with the "spaghetti" option from the study of Forde et al. (2017). The variability of eating rate was greater in

Table 4
Multiple regression analysis for energy intake of Test Meal 2 (*ad libitum* lunch), N = 76.

Energy Intake,	B	95% CI for B		SE B	β	R^2	ΔR^2
N = 76		LL	UL				
Model						0.485	0.440
Constant	−274.713	−973.764	424.338	350.411			
Age	2.330	−5.979	10.639	4.165	0.051		
Gender	0.249	−96.254	96.751	48.374	0.001		
BMI	10.039	−3.636	23.715	6.855	0.138		
Eating rate	14.325***	9.981	18.668	2.177	0.652***		
Test Meal 2 liking	0.414	−2.068	2.897	1.244	0.031		
Overall appetite iAUC	−0.023	−0.076	0.029	−0.079	−0.079		

Multiple regression analysis results for N = 76. B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE B = standard error of coefficient; β = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R2; $p < 0.05$, **$p < 0.01$, ***$p < 0.001$; $p < 0.05$ is considered statistically significant.

older adults, as the coefficient of variation (CV) was 10% greater for the Test meal 1 comparisons (CV 34.1% for scrambled egg sandwich versus CV 24.1% for soft sandwich) and 3% greater for the Test meal 2 comparisons (37.2% CV for pasta in this study versus 34.3% CV for spaghetti). This greater variability in the older adults' group may be due to the diversity in the ageing-related decline in oro-sensory, physiological functions and physical abilities (Brownie, 2006).

This study explored the natural variability in OPBs and associations with energy intake and appetite among a large group of older adults, which included an equal number of male and female participants, allowing exploration of possible gender influence on the research questions. The limitations of the study are reported below. The study included participants living in the wider geographical area of Berkshire (United Kingdom), which limits the sociodemographic representation and further generalizability of the results. Despite commonly consumed food products were used and participants were instructed to eat in their natural way in both meals, eating experience may have been influenced by the methodologies used (video recording during Test Meal 1, frequent food bowls' replacement during Test Meal 2 but also the measurements and tests in between the two meals). However, methods were consistent for all participants. Another limitation is that the study's approach utilised a cross-sectional design, which does not allow for assertions of causality. To further support the accuracy of the estimated eating rate of Test Meal 2, we assessed the ICC with the calculated eating rate (from the video recordings) of Test Meal 1, and a significant but poor correlation was observed ($r < 0.5$; considered a poor correlation as per Koo & Li, 2016), meaning a low degree of agreement between the two measurements of eating rate across the two meals. This can be explained by the different methodologies and different foods used in the two meals, which may have affected the eating behaviour. Eating rate is consistent when the same meal is consumed on different occasions (McCrickerd et al., 2017) but this has not been explored between different meal items; thus, it is possible that individuals' eating rates differ between different meals. Furthermore, due to the limited timeframe of the study, a familiarisation session was not included, which could have introduced the experimental setting and processes to participants and could have affected the measured eating behaviours and meal intake (Roberts et al., 2006) and possibly improved the ICC between the meals. However, many of the participants were part of the university participants' database and were familiar with the study environment and some of the methodologies used in the study. Lastly, eating rate data of the lunch meal were missing for 12 participants due to inability to retrieve their duration of the *ad libitum* meal.

Future studies in this age group, should further explore the effect of eating rate and oral processing on metabolic markers that are involved on food and energy intake and appetite regulation paths, such as postprandial blood glucose and insulin responses as well as gastric emptying rates. Future research focus should also shift towards the "slower eater" older adult groups as well as the "frail" older adults, who would be benefited the most by interventions on eating rate of foods. Specifically, target older adults' populations may include those being identified as appetite deprived, malnourished or at risk of malnutrition, individuals in care homes and hospital settings and those suffering with serious oral conditions.

5. Conclusions

This study explored individual variations in food oral processing in older adults and showed significant association between a faster eating rate and greater energy intake at the same meal. Gender related differences, as well as differences between faster and slower eaters were also found in the OPBs explored. The present study's findings can provide useful insights on oral processing, food intake and appetite in the understudied population of older adults. Future interventions should explore ways to increase eating rate and food intake in the older adults' subgroups that are in need of greater nutritional intake. Settings such as care homes and hospitals can be used for future targeted interventions, to promote food solutions and approaches, that can increase those older adults' eating rate, food and energy intake.

CRediT authorship contribution statement

Dimitra Zannidi: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Lisa Methven:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jayne V. Woodside:** Writing – review & editing, Visualization, Software, Resources, Methodology, Funding acquisition, Data curation. **Gerry McKenna:** Writing – review & editing, Visualization, Software, Resources, Methodology, Funding acquisition, Data curation. **Ciarán G. Forde:** Writing – review & editing, Visualization, Software, Resources, Methodology, Data curation. **Miriam E. Clegg:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethical statement

The study was performed in accordance with the Declaration of Helsinki and was granted ethical approval from the University of Reading Research Ethics Committee (UREC 22/29, 22/10/22). Written, informed consent was obtained from all participants at the beginning of the visit, before any data collection commenced.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2025.107917.

Data availability

Data will be made available on request.

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